Updates on PEGASAS Project 36: Weather Information Risk and Uncertainty Resolution

Presented by
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2025 PEGASAS Annual Meeting

Although the FAA has sponsored this project, it neither endorses nor rejects the findings of this research. The presentation of this information is in the interest of invoking technical community comment on the results and the conclusions of the research.

The Team

- Technical monitors: Gary Pokodner, Dr. Ian Johnson
- PEGASAS lead PI: Dr. Barrett Caldwell (Purdue)
- Florida Tech PI: Prof. Michael Splitt
- Students
  - Evv Boerwinkle (Purdue)
  - Robbie Breininger (Florida Tech)
  - Marcus Cote (Florida Tech)
  - Emily Happy (Florida Tech)
  - Cassandra McCormack (Purdue)
  - Hetal Rathore (Purdue)

Previous Study

- Previous decision-making study at WJHTCAA aimed to understand how visibility impacted pilot's decisions of "go/no-go" and their confidence in that decision based on their ability to identify weather conditions

- Findings in predictions of risk and uncertainty based on information availability was unexpected
    - Pilots demonstrated insufficient skills in estimations of correct flight rule categories
    - Increases in observability did not improve accuracy or confidence

Motivation / Need

- This project addresses challenges with pilot assessment of weather conditions located between known ASOS / AWOS reporting stations, particularly in areas of complex terrain or land cover, which can impact weather conditions along flight plan routes. These may be poorly interpolated by many aviators, including experienced pilots with knowledge of low-altitude operations (LAO) and how complex terrain features can impact weather conditions at low altitudes

Project 36 Motivation

- Project 36 aims to further understand weather-related pilot decision-making processes

- Focus on changes in decision making as display resolution is increased
  - Do pilots understand weather display information elements they use? Do they trust them?

- Compare differences and benefits of various types of display information elements
  - What display characteristics do they find useful?

Project 36 Status Update

- Project 36 considers
  - Low altitude operations (LAO) and terrain variation effects
  - Weather uncertainty and risk along entire flight path
  - Potential implications and uses of machine learning for weather-related applications (MLWx)

- Progress
  - Identified relevant regions with weather interpolation and risk uncertainty variations of interest
  - Developed and delivered experimental study materials for part-task research study activity at FAA WJHTC

Research Objective(s)

- Task 1: Additional study areas in regions of geographic interest and utilization of weather, ecological, and geophysical zone backgrounds for a second survey of pilots at the FAA WJHTCAA.

- Task 2: Continued development of machine learning applications for 1) hazardous cloud type identification and 2) flight rule category conditions to highlight and resolve uncertainty in local weather conditions between stations
    - *Applications to a recent incident near San Diego (May 2025)*

Project 36 Task 1 Update

- Upcoming
  - Data collection – Implementation of experimental design through a part-task research study at FAA WJHTCAA this summer
  - Submission of final report and recommendations

Static Weather Displays

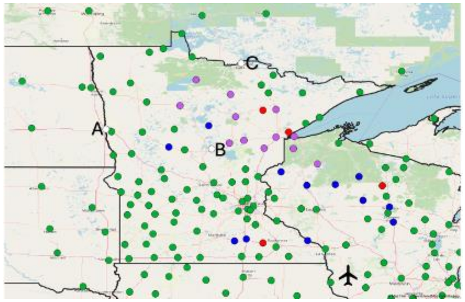
- Three regions of interest
  - Northern Plains
  - Great Lakes
  - Southern Appalachian
- Three levels of resolution
  - Low level
  - Medium level
  - High level
- Three data layers
  - VFR wall planning chart
  - Geophysical Map
  - Open Street Map

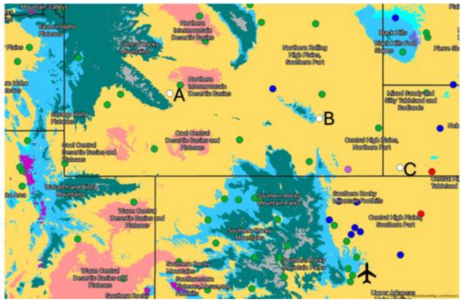
Data Layers	Destination Points		
	A	B	C
Low Resolution			
VFR Wall Planning Chart			
Climate Map			
Open-Street Map			
Medium Resolution			
VFR Wall Planning Chart			
Climate Map			
Open-Street Map			
High Resolution			
VFR Wall Planning Chart			
Climate Map			
Open-Street Map			

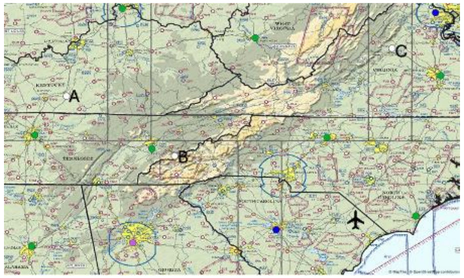
	OVERALL			
	VFR	MVFR	IFR	LIFR
LOW RES	144	57	10	5
MED RES	112	89	12	3
HIGH RES	36	154	26	0

Upcoming survey at the **FAA WJHTC**

- Flight Rules Category estimation at a known location or incident location
  - VFR, MVFR, IFR, LIFR
- Updated from the past survey to include meteorological/geophysical background layers that may influence a pilot's decision making
  - Open Street Map Layer
  - Geophysical Elements Layer
  - VFR Wall Map Layer
- Data provided at increasing resolution on each of the background layers
- Additional geographic study regions







Experimental Design

- Part-task experimental study designed to investigate weather-related information perception of GA pilots
  - Survey questions seek to understand perception, cognition and decision-making processes of GA pilots
  - Experienced pilots with different type ratings stratified by age group

- Experimental structure
  - Preliminary demographics and experience survey
  - Decision-making task based on strategic presentation of static weather displays to estimate correct flight rules category
  - Debriefing questions to assist in qualitative analysis

Flight Rule Categories

Category	Ceiling		Visbility
Visual Flight Rules VFR (green sky symbol)	Greater than 3,000 feet AGL	and	Greater than 5 miles
Marginal Visual Flight Rules MVFR (blue sky symbol)	1,000 to 3,000 feet AGL	And/or	3-5 miles
Instrument Flight Rules IFR (red sky symbol)	500 to below 1,000 feet AGL	And/or	1 mile to less than 3 miles
Low Instrument Flight Rules LIFR (magenta sky symbol)	Below 500 feet AGL	And/or	Less than 1 mile

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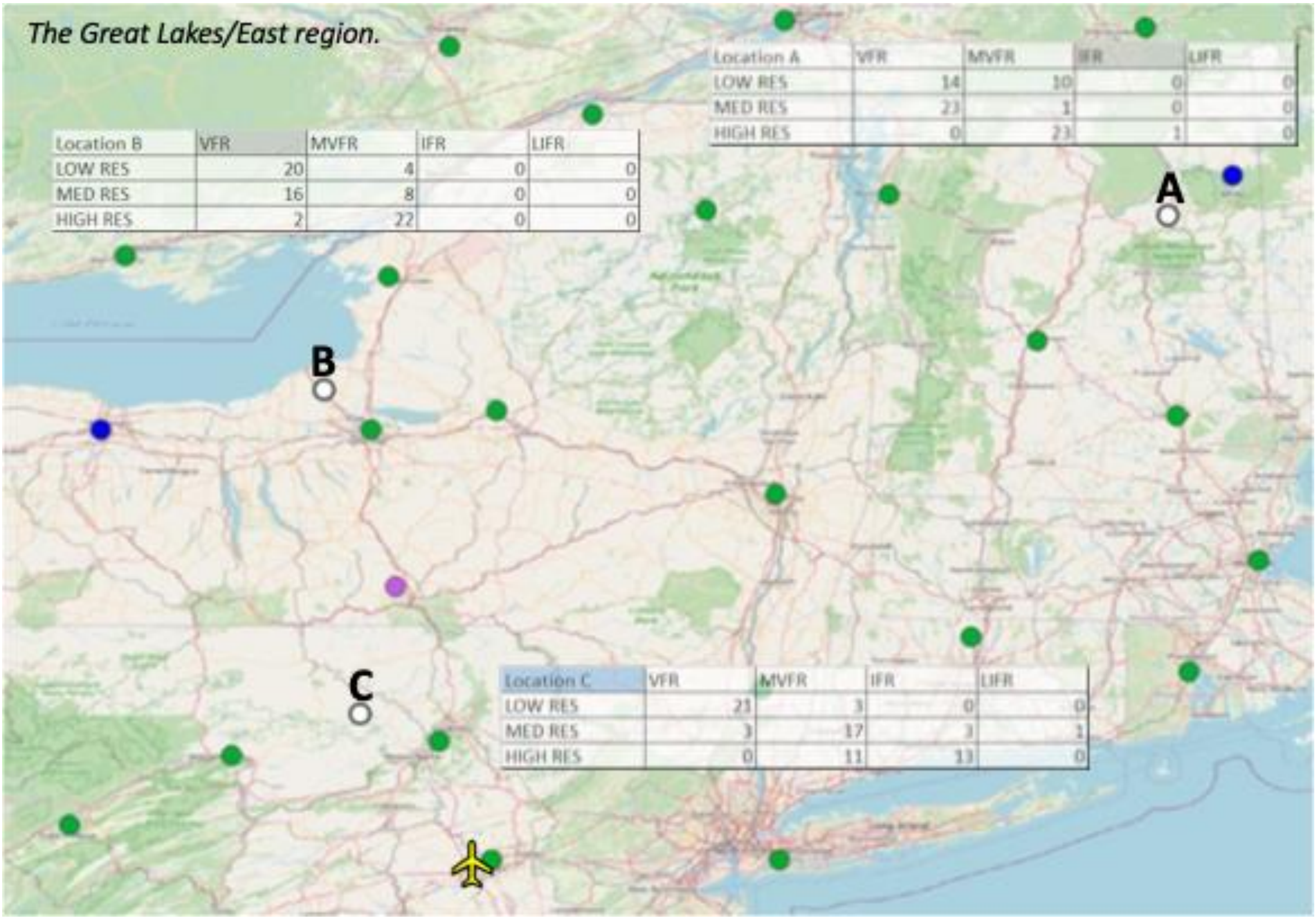
Low Resolution

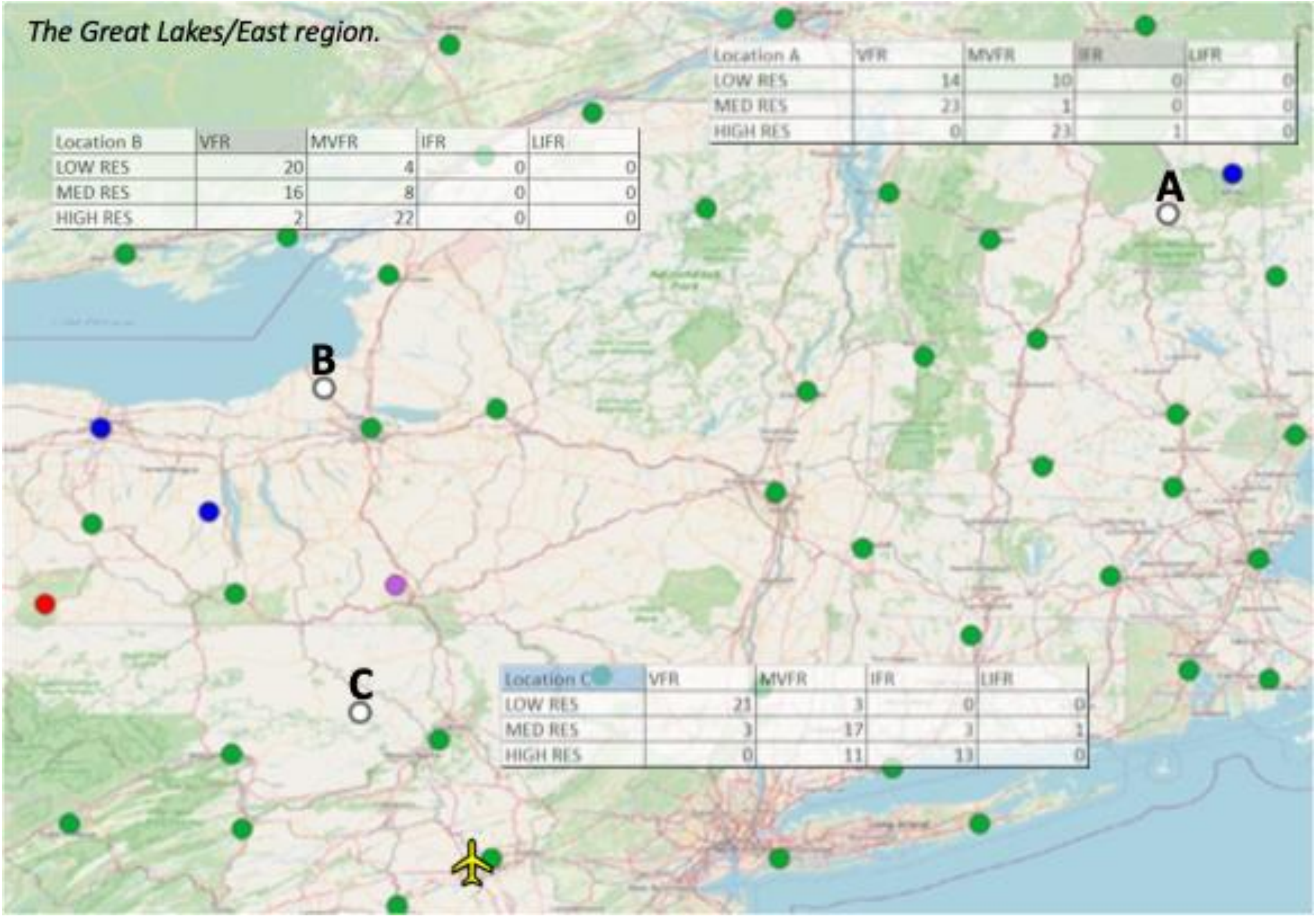


Location A	VFR	MVFR	IFR	LIFR
LOW RES	14	10	0	0
MED RES	23	1	0	0
HIGH RES	0	23	1	0

Location B	VFR	MVFR	IFR	LIFR
LOW RES	20	4	0	0
MED RES	16	8	0	0
HIGH RES	2	22	0	0

Location C	VFR	MVFR	IFR	LIFR
LOW RES	21	3	0	0
MED RES	3	17	3	1
HIGH RES	0	11	13	0

Medium Resolution



Location A	VFR	MVFR	IFR	LIFR
LOW RES	14	10	0	0
MED RES	23	1	0	0
HIGH RES	0	23	1	0

Location B	VFR	MVFR	IFR	LIFR
LOW RES	20	4	0	0
MED RES	16	8	0	0
HIGH RES	2	22	0	0

Location C	VFR	MVFR	IFR	LIFR
LOW RES	21	3	0	0
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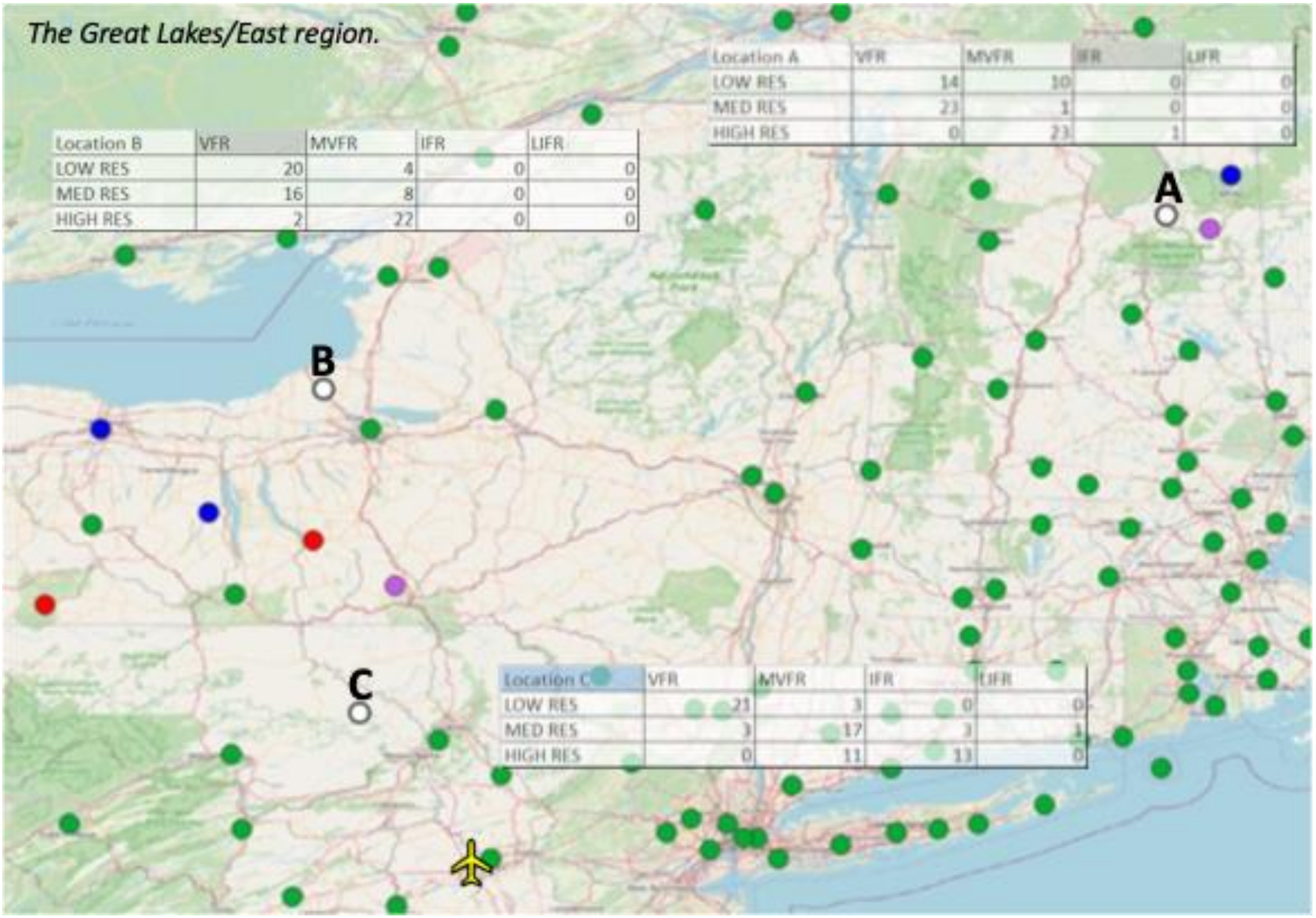
High Resolution



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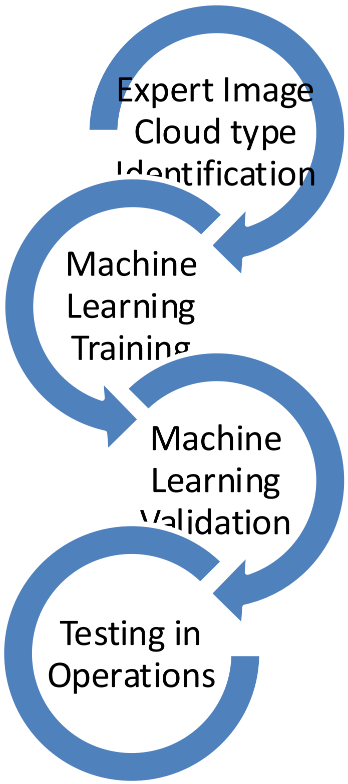
Experimental Design

- 72 experienced pilots (>500 hours) participate in part-task survey in fully blocked Latin Square design
- Three regions of interest considered for three different data layers with increasing levels of resolution
    - Sequence of 27 images (3 regions x 3 data layers)
    - Regions of interest and data layers are randomized for each participant
    - Three levels of resolution (low/medium/high) are sequentially displayed
    - Participants take a break between each set of 27 images to avoid decision-making fatigue
- Participants required to estimate the correct weather flight rules category conditions – VFR, MVFR, IFR, LIFR

Project 36 Task 2 Update

- Current and Upcoming
  - Ongoing Machine Learning Algorithms Development
  - Application of Algorithm to untrained (real) event
  - Submission of final report and recommendations

Cloud Type Machine Learning: Methods



- Developed a meteorological hazards-oriented WEBcam Clouds for Aviation Meteorology (WEBCAM) dataset.
  - The WEBCAM dataset is currently composed of images from the FAA, AirportView, and AlertCalifornia webcam networks.
  - The categories are altocumulus (Ac), cumulonimbus (Cb), Cirrus (Ci), clear sky (Clear), fair-weather cumulus (Cu), fog/obscuration (Obsc), rain/precipitation (Precip), stratus (St), and towering cumulus (TCu).
- Developed and tested our Convolutional Learning for Observing and Understanding Diverse Skies (CLOUDS) machine learning model.
- Surveyed pilots at Sun N' Fun on cloud images in which they would like to receive alerts.

Cloud Type Machine Learning: Results

- Model Accuracy:
  - Cloud specific @ 83.8%
  - Hazard specific @ 94.2%
- Cloud identification data shared with MITLL for use in ceiling estimation

Model top-1 prediction	Categorized validation images (truth): Nonhazardous	Categorized validation images (truth): Hazardous
Nonhazardous	**Correct negatives: 96.7% (1838/1900)**	Misses: 9.7% (117/1207)
Hazardous	False alarms: 3.3% (62/1900)	**Hits: 90.3% (1090/1207)**

Accuracy: 94.2%

	Categorized validation images (truth)								
	Nonhazardous				Hazardous				
	Ac	Ci	Clear	Cu	Cb	Obsc	Precip	St	TCu
Image total:	403	451	520	526	150	378	205	262	212
Model top-1 prediction: Ac	**357**	55	9	18	5	0	2	3	5
Ci	28	**354**	26	14	4	0	0	0	0
Clear	4	14	**478**	7	1	0	1	0	1
Cu	8	17	5	**444**	27	0	4	0	64
Cb	0	4	0	8	**44**	0	2	0	18
Obsc	0	0	0	0	0	**370**	0	0	0
Precip	0	1	0	1	3	6	**194**	17	0
St	6	0	0	3	1	2	2	**242**	2
TCu	0	6	2	31	65	0	0	0	**122**
Top-1 Accuracy	88.6 %	78.5%	91.9%	84.4%	29.3%	97.9%	94.6%	92.4%	57.5%
Cumulative top-1 accuracy: 2605/3107 = 83.8 %									

Cloud Type ML Early Detection of TCU

The following case occurred on 26 July 2023 at the Melbourne-Orlando International Airport in Melbourne, FL (KMLB).

KMLB is home to NEXRAD WSR-88D, ASOS, and WX Cameras.

A machine learning prediction of cloud type is provided for the following WX camera images by the Florida Tech CLOUDS model.

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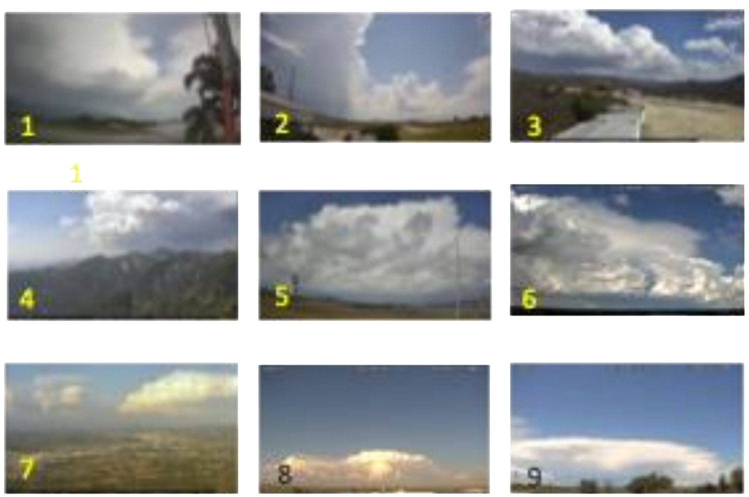
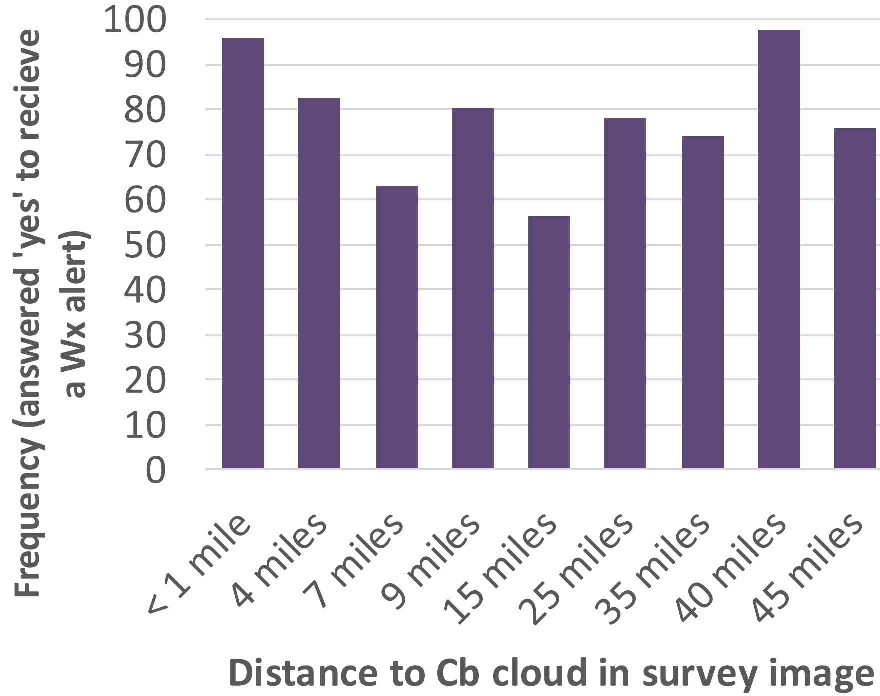
Sun N' Fun Survey: Pilots' perception of actionable CBs

IF THIS IMAGE WAS TAKEN AT AN AIRPORT THAT IS EITHER YOUR DEPARTURE OR DESTINATION, WOULD YOU WANT A WX NOTIFICATION? YES or NO





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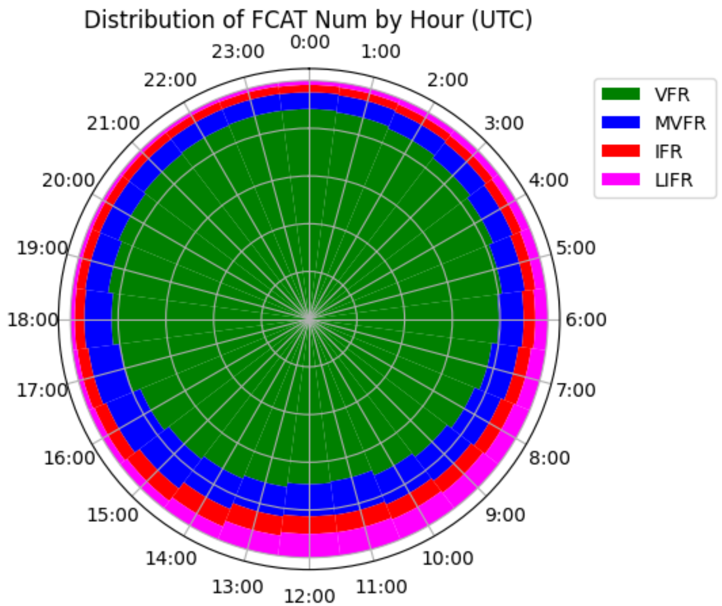
BiLSTM ML for Prediction/Risk Assessment

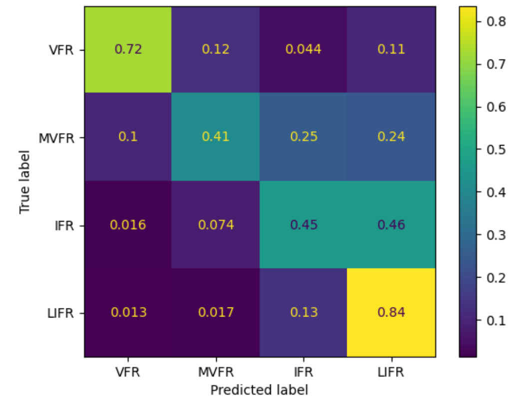
- Goal: Use of machine learning to predict conditions/risk
  - At an ASOS/AWOS that reports weather but may be temporarily missing
  - At a mesonet location which doesn't report ceilings and visibility
  - At an undefined location
- Methods: Bidirectional Long-Short Term Memory (BiLSTM) ML
  - ASOS Data (hourly METARs) in two focus regions
    - CPSA: 5 years (2019-2023) 150+ stations
    - SoCal incident: 6 years (2019-2024) 8 stations
  - Test: Predict Flight Rule Category condition at a specific ASOS
  - ML Training and Validation:
    - For CPSA, trained on 4 years, tested on 1 year
    - For SoCal, trained on 5 years, tested on 1 year
  - Features:
    - Temperature, Wind Speed, Relative Humidity
    - Geophysical Elements
  - Labels:
    - Flight Rules Category (FCAT)



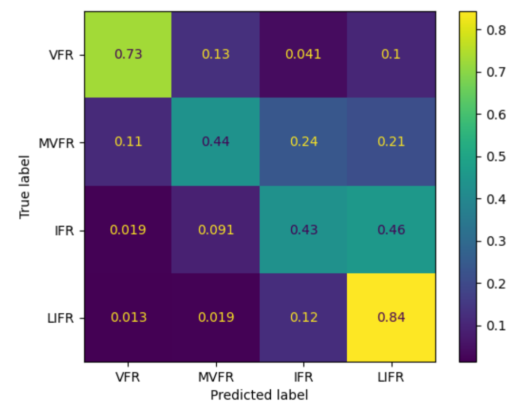
BiLSTM ML Results

Results for the Columbia Plateau/Southern Appalachian (CPSA) region

- Test 1
  - 37 stations (with most complete data records)
  - No geophysical elements used as features
  - 24-hour sequences
  - Penalty for “under-prediction”.
    - We’d rather error on the side of predicting a worse category vs. a better category.
  - Most data along the optimal diagonal except for the model tendency to predict LIFR in IFR conditions.
- Test 2
  - As above, but use of FJ Physiographic and Plant Hardiness zones as features
- Test results
  - Overall prediction of FCAT maximizes along the diagonal
  - Weather/physiographic (geophysical) zone usage, ***in this context***, did not noticeably improve predictive capability



Control



Including Geophysics

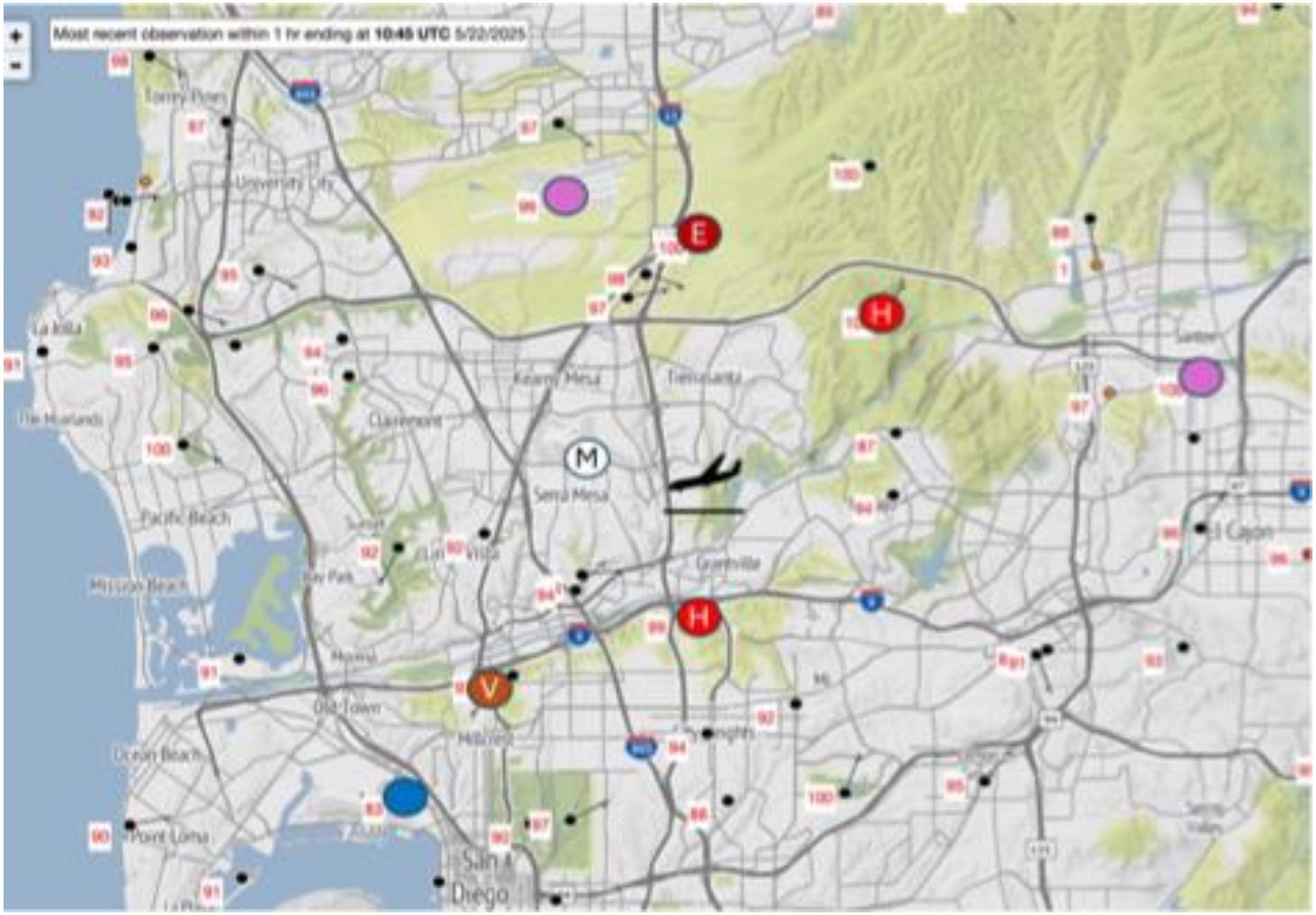
N666DS Accident on Approach to MYF

- A Cessna S550 Citation S/II, N666DS, was destroyed when it crashed while on approach to runway 28R at Montgomery-Gibbs Executive Airport (MYF/KMYF), San Diego, California. May 22, 2025 at 3:47 am PDT, 10:47 UTC
- According to air traffic control data, during the final portion of the flight, the pilot(s) enquired about the conditions at other nearby airports, because the ASOS at KMYF was not working
- Applications of past and ongoing Project 36 work
  - Risk assessment using ASOS ceilings and mesonet relative humidity reports
  - Neural network machine learning

Risk Assessment Matrix using ASOS Ceilings and Mesonet RH

Distance to ASOS/AWOS	Cloud layers	Mesonet RH> 98%	Mesonet RH> 95%
Less than or equal to 10 SM	Ceiling and/or an additional BKN or OVC layer within 200 feet of the mesonet altitude	Very High	High
Less than or equal to 10 SM	Ceiling and/or an additional BKN or OVC layer within 500 feet of the mesonet altitude	High	Moderate
Less than or equal to 20 SM	Ceiling and/or an additional BKN or OVC layer within 200 feet of the mesonet altitude	High	Moderate
Less than or equal to 20 SM	Ceiling and/or an additional BKN or OVC layer within 500 feet of the mesonet altitude	Moderate	Caution
	Multiple ASOS/AWOS comparisons in the Very High risk category.	Extreme	

Risk Assessment from data available at incident time



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Summary and Upcoming Projects

- Previous PEGASAS research has identified the following gaps
  - Pilot knowledge, skills and abilities (KSAs)
  - Weather information presentation
  - Pilot interpretation and recognition of weather variations between authorized airport-based (AWOS/ASOS) reporting stations
- To address these gaps the following amendment and project proposal were added to current baseline Project 36
  - PEGASAS PROJECT 36 AMENDMENT/AUGMENTATION
  - PEGASAS NEXT

Project 36 Augmentation

- Amendment / Augmentation to Project 36 aims to integrate machine learning capabilities to support pilot decision-making
  - Purdue team has written a literature review for weather display presentation strategies for ML-based weather applications for aviation
  - Florida Tech team has been applying ML algorithms to cloud datasets for correct cloud type classification
    - Sun N Fun Cloud Survey

PEGASAS NEXT Proposal

- PegNext aims to explore and provide pilots with additional sources of weather information to assist in terrain-related conditions
  - Example sources – established traffic cameras, fire/flood condition monitoring stations, first responders for a search and disaster response mission
- PegNext seeks to understand pilot acceptance, understanding and use of different types of weather sources
  - Fixed vs Mobile weather sources
  - Human vs Automated/ML weather sources
  - Directive vs Exploratory approaches to decision-making

PegNext – Directive vs Exploratory Decisions

- Directive vs Exploratory Decision-Making
  - Understanding if pilots approach decision-making with a directive vs exploratory attitude can help design the right kinds of support tools and products to assist pilots with weather-based decision making
  - Directive use – a go/no-go decision is made based on observation of various weather sources
    - Heuristic like decision-making
  - Exploratory use – understanding why a go/no-go decision is made based on observation of various weather sources
    - Deeper level of understanding behind decision-making process